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GEOLOGY AND LAND RECLAMATION^{1, 2}

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ABSTRACT

Expansion of the population in the periphery of urban centers creates increased need for land for food, housing, recreation, and waste disposal. As much of land is occupied, derelict lands such as floodplains, swamps and bogs, abandoned mineral workings, and steep slopes are subjected to reclamation.

Reclamation of wetlands for agriculture in north-central United States is accomplished simply by land drainage. Reclamation of derelict land (wetlands, floodplains, stripped land and quarries, and landslide-prone slopes) for municipal, industrial, or residential needs requires study by environmentally oriented scientists as well as engineers, to prevent environmental disruption. In Illinois and Ohio, reclamation or intensive use of some derelict lands has precipitated problems of flooding, surface-water pollution, ground-water pollution, and landslides. Study of the geology and hydrology of the area considered for reclamation prior to construction is highly desirable for making more effective reclamation and for deciding on the best land use after reclamation. Low-intensity land uses such as parks on floodplains, agriculture in old strip-mined areas, and ski runs on unstable slopes may be, at least for the present, the highest value land-uses available for these sites.

INTRODUCTION

Land reclamation means the modification of inadequate land area, by levelling, draining, etc., so as to permit man to use that land. The practice of land reclamation has changed since the 1940's, because of increasing demand for industrial, residential, and recreational land near urban centers. Prior to the last two decades, land reclamation embodied land drainage, flood protection and prevention, and irrigation primarily to further agriculture. Today, floodplains, swamps, abandoned mineral workings, and geologic hazard areas are modified to meet man's increased demands for more intensive uses.

Reclamation of much of this land is essential to feed and house the populace of the United States. However, in certain environments, reclamation can upset an existing ecological balance, cause water pollution, or create a geologic hazard. Thus, any geologist, engineer, planner, or soils scientist actively involved with land reclamation needs to consider more than just the mechanics of levelling or draining land for human use. Similar land reclamation problems are encountered in Russia. According to Barklaya (1970), the main shortcoming of reclamation projects in Russia is the poor quality of the related geological and hydrological investigations. Modern land-reclamation projects need to be guided by studies made by environmentally oriented scientists. This paper illustrates some land-reclamation techniques and some possible contributions to the art by environmental scientists.

DERELICT LANDS

The term "derelict lands" (Oxenham, 1966) describes areas which in the opinion of man are not best serving his immediate needs and might be considered

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for reclamation. The farmer might think of marshes, swamps, and frequently flooded river lowlands as derelict, because of drainage problems. Land developers also consider these wet areas to be derelict. Areas left unsightly by surface mining, dredging, or clear-cut timbering are generally considered to be derelict, as they must be reclaimed for almost any use. Lands in this category are seldom pleasing to the view and detract from the aesthetic value of a region.

Geologic-hazard areas, upon which human habitation or utilization could be hazardous or economically unfeasible, are derelict. This category includes landslide-active slopes, floodplains, and regions underlain by large solution cavities or old unmapped mine tunnels. Areas with very thick, highly compressible soils such as peat are economically unfeasible for many types of construction and thus might be considered to be derelict.

RECLAMATION TECHNIQUES

The first settlers to come into the glaciated area of northwest Ohio, Indiana, Illinois, Iowa, and Missouri were confronted with thousands of miles of intermittently flooded prairie lands. To settle and farm the land, drainage was essential. Drainage prior to 1835 consisted of ditching and cleaning out of stream channels (Wooten and Jones, 1955), and was effective only on lands with considerable natural gradient. With the advent of the use of drain tile in 1835, large areas could be efficiently drained and reclaimed.

Small perennially wet depressions were frequently left in a natural state because of the difficulty associated with drainage. In addition, these small areas, many less than 10 acres in size, were not economical to reclaim for farming. Today, the same small bogs and swamps can be economically drained and levelled and developed for non-agricultural purposes. The limiting factor for their reclamation in the past, the factor of low economic return for high expense, is not valid with present land values near cities. Many bogs and swamps in northeastern Illinois are now golf courses, ball fields, and parking lots.

Protection of floodplains by construction of dams, dikes, levees, floodwalls, and channel improvements is impressive and costly, without achieving complete flood control. Floodflows prevented from expanding onto floodplains by levees, dikes and floodwalls have ever higher crests as they move downstream. Where the floodwaters can finally escape from the channel, the floods are higher than are floods in unprotected streams. The public, with complete faith in the flood protection provided, which in many cases was only designed to protect agricultural lands, has rushed in with construction right to the river bank, unaware that, although the frequency of flood damage may have been reduced, flooding as a hazard has not been eliminated, and, where restrictive levees have been built upstream, may even be worse than in the past (Howe, 1969). Millions of acres of floodplain reclaimed for agriculture are now occupied by cities, such as Kansas City, East St. Louis, and Davenport.

As long as land was cheap and reclamation bonds were not required, coal-stripped lands, gravel pits, and rock quarries were abandoned when operations ceased to be profitable or when the deposit was mined-out. Frequently taxes were defaulted on the derelict land and the property reverted back to the county, state, or Federal Government. Many local rock quarries or sand and gravel pits, when flooded, became "swimming holes," such as that shown in Figure 1. Such unreclaimed quarries can be extremely dangerous for swimmers because of deep water, with sheer, jagged rock walls, and an uneven rocky bottom. Figure 1 shows a ladder placed on a ledge which provides the only way out of the quarry. Unfortunately, many accidents occur every year in quarries such as this. Sand and gravel pits commonly have unexpected dropoffs into deep holes, creating hazards for non-swimmers or poor swimmers.

Unreclaimed dry quarries have been used as city dumps, septic-sludge recep-

tacles, and target ranges. In the first two examples, pollution of ground water by leachate and effluent from the waste can and does occur (Hackett, 1965). Fortunately, some dry quarries have been reclaimed by being made into city parks simply by levelling the floor of the old site, adding top soil, and planting grass.

Past reclamation of geologic-hazard areas was commonly not adequate. In areas with landslide-active slopes, reclamation consisted of tree or shrub plantings



FIGURE 1. Abandoned limestone quarry used as a swimming pool, representing an unsafe recreational use of derelict land.

in the hope that their roots would stabilize the active slopes, a method which had only limited success. Solution cavities in southern Indiana and north-central Ohio were viewed as holes to be filled with waste, covered with top soil, and farmed. This method did not prevent any additional collapse, and only masked the problem, and in many cases provided opportunity for wastes to rapidly reach the ground-water level.

GEOLOGY AND LAND RECLAMATION

Sound land-reclamation techniques today require geological and ecological data, in addition to engineering data, to provide the area with a land use compatible with the environment. Examples are presented to illustrate what geologic data should be collected for specific reclamation projects.

Floodplains

The best engineering works do not make floodplains completely safe for the development of subdivisions, industries, or municipalities. In addition, restriction of flood waters by levees upstream creates higher, potentially more damaging floods downstream. Therefore, floodplains should not be considered as reclaimable for such uses. Floodplains can, however, be used for low-risk recreational developments, such as golf courses, tennis courts, ball fields, picnic grounds,

parking lots, and green belts. The Forest and Parks Division of Cook County, Illinois, has purchased large acreages of floodplain along the Des Plaines River for use as open space. Hiking trails, picnic tables, and parking areas are the only additions to the natural floodplain in most of the area. Thus the yearly flood causes little damage and little concern.

The function of the geologist and hydrologist relative to reclamation or management of the floodplain is to map clearly and accurately the extent of the floodplain and to define flood risks. The flood risk is the percent chance that a flood crest will equal or exceed a certain elevation in a specified interval of years. Frequencies can be expressed as probabilities which can define the risk for certain properties; for example, a given area may have a 50-percent chance of being inundated by flood waters each year (Shaeffer, Ellis, and Spieker, 1970). Floodplain maps that show areal flood risks are designed to provide data for the orderly development of lands subject to flooding (i.e., uses compatible to occasional flooding). Flood-hazard maps are presently used by the Veterans Administration and the Federal Housing Administration to evaluate locations of new housing developments which they are considering financing (Sheaffer, Ellis, Spieker, 1970). Those developments in high-flood-risk areas are not financed.

Unfortunately, a flood-hazard map prepared in 1960 for a watershed undergoing extensive urbanization may be out of date in 1970. The volume and frequency of flood flows increase with the addition of impermeable surfaces, such as highways, parking lots, houses, etc., to the watershed. One of the tasks of the hydrologist is to prepare flood models of the watershed, so that the effect of each additional impermeable area on surface-water runoff can be estimated (Ackermann, 1969). The flood model is a mathematical model that is readily applicable to computer analysis. The constant inputs into the model are the geomorphic characteristics of the watershed, such as slope, drainage density, and soil type. Evaporation and transpiration rates, precipitation, and ground-water flow are variables that determine the actual quantity of water flowing in a watershed in response to a rainshower, and the elevation of the water in the stream channel is directly proportional to that quantity of water. The change in flooding frequency in a watershed brought about by land-filling, excavation, and construction of dwellings can be determined with the model, as these are effectively geomorphic changes. Thus the effect of any flood plain development can be evaluated prior to initial actions on the floodplain. The best use for the floodplain can be determined based on results of the model study.

Wetlands

Wetlands is a collective term for all land areas covered with shallow water or subjected to intermittent flooding and subsequent slow drainage (Baker, 1960). Wetlands are generally characterized by deposits of organic matter. To many people, wetlands are derelict land, and government officials are usually pleased with the prospect of an increased tax base when developers come in with plans to fill this land (Whyte, 1968). However, drainage and filling of certain wetlands can adversely affect both the hydrologic and the ecologic systems of the area.

Upland lakes, swamps, and bogs capture and store a portion of the direct runoff from a storm, thereby reducing the flood crest in the main stream channel. A portion of the stored water is evaporated from the wetlands surface, and another portion is adsorbed by plants and is then given off from the plants by transpiration. A small quantity of the water may recharge the ground-water level during dry seasons. Wetlands associated with floodplains capture and detain some of the floodwater and provide area for energy dissipation of the flood, which reduces the flood level and results in silt deposition.

Wetlands serve as feeding and breeding areas for shellfish, fish, and waterfowl

in coastal regions; in the interior, they serve as wildlife refuges and botanical preserves. The inaccessibility of many wetland areas has made them wildlife sanctuaries. The duck population of central United States is dependent on marshes, swamps, bogs, and "potholes" in Wisconsin, Minnesota, South Dakota, North Dakota, and Canada. Drainage and development of the prairie potholes in Minnesota and the Dakotas reduced the duck population by as much as 10 million by 1955 (Schrader, 1955). Although man-made lakes and ponds provide water space for waterfowl, recreation pressure is usually so high that the waterfowl will not use the lake.

In light of the hydrologic and biologic functions of wetlands, reclamation by draining and filling should only take place after a careful study of the effects of this action on the area. Even if the decision is made to preserve a wetland, investigation may be made to determine the wetland's response to development in the peripheral region. An example of such an investigation follows (taken from report by McComas, Kempton, and Hinkley, In press).

A developer purchased land adjacent to one of two remaining tamarack bogs in Lake County, Illinois. Original plans for proposed reclamation outlined a program of land drainage, filling, construction of residences, and development of a golf course. The writer, as an employee of the Illinois State Geological Survey, was asked to study the hydrology and geology of the bog, and to determine the bog's response to development of adjacent properties.

This Lake County bog is situated in a deep undrained natural depression, with surrounding uplands underlain by coarse sand and gravel, some of which has been extracted. Because of the high permeability of these upland deposits, most precipitation infiltrates and recharges the bog by ground-water flow. No surface-water streams flow into the depression. Overland flows of surface water occur only during high-intensity rains or when the ground surface is frozen or completely saturated. The remaining recharge to the bog is precipitation that falls on the bog.

Upland ground water is alkaline, whereas water in the bog is acid. The acidity is believed to be gained during movement of the ground-water through the organic material in the bog. Flora in the bog are dependent on acid water. Residential development in the upland area would reduce the permeable area and thus reduce ground-water recharge and infiltration of precipitation, so that surface runoff would increase. A large increase of alkaline surface water to the bog could upset the alkaline-acid balance of the waters, which is presently maintained by the bog plants. Such a change in water chemistry would be sufficient to destroy the ecological balance of the bog. Drainage of the property surrounding the bog would have the potential effect of permanently lowering the water level in the bog (McComas, Kempton, and Hinkley, In press). A permanent water-level decline in the bog, together with the increased alkalinity of waters feeding it, would effectively destroy it. Draining in the peripheral area and pumping water into the bog to maintain the bog water level would add also undesirable alkaline water to the bog.

The results of the study showed that, if the developer proceeded with his reclamation plans for the area peripheral to the bog, he would essentially destroy the ecosystem of the bog. A legal decision was made by the Lake County, Illinois, court that the bog should be preserved as a natural resource of the County. As little work could be accomplished in the adjacent lands without affecting the bog, the development project was abandoned.

Strip Mines

The major emphasis in strip-mine reclamation is to reduce or eliminate potential for acid drainage and sedimentation (Brooks, 1966). In addition, the ugly scar of barren dumps, deep cuts, and highwalls produces an unsightly landscape,

which needs reclamation measures. The principal methods for eliminating acid drainage employ techniques to prevent oxidation of the iron-sulfide minerals in the waste piles. Burying the iron-sulfide-bearing waste in the deepest part of the strip mine, or damming the strip mine to keep the waste beneath captured surface-water runoff are some frequently used methods to prevent acid formation. To reduce erosion and enhance the landscape, sedimentation slopes are leveled and planted. The details of soil building, soil treatment, and actual planting are described in detail in several papers (Limstrom, 1964, Smith *et al.*, 1964).

Land reclaimed by these methods can be suitable for tree farming, certain row crops, and recreation. With the demand for moderate-income housing in recreational areas, and for cheap land for solid-waste disposal, many thousands of acres of such stripped and reclaimed land are considered for uses other than agriculture or recreation. Use of stripped land for waste disposal can serve two purposes: one, to dispose of ever-mounting solid waste, and two, to reclaim land using waste as a construction material. However, random disposal of solid or liquid waste in deep excavations left by surface mining can be detrimental to the environment. Of particular concern is the chance that contaminants from the waste may be able to seep down into the groundwater. The site must be fully evaluated prior to disposal operations.

A good example of the questionable use of a stripped area as a summer recreation area in Goose Lake Village near Coal City, Illinois. This area received national publicity as a good example of a reclaimed strip-mine when Mrs. Richard Nixon visited the site in 1970. The village is well designed, with house lots placed along a long, winding lake. Many of the lots were cut out of waste piles left by the stripping. Three geologic problems were overlooked in the development of this village. These are: the low infiltration capacity of the weathered surface materials, the chemical quality of the ground water, and the questionable stability of some of the waste piles.

The weathered shale which constitutes much of the material at the surface is relatively impermeable and thus creates a problem, because septic systems do not readily drain through it. The low percolation rate of fluids through this weathered shale results in return of the effluent to the ground surface, and surface movement of the effluent into the lake. Home owners in Goose Lake Village have complained to drillers about poor quality water in wells. The writer found well water in a Goose Lake home to have a strong sulfur smell and a slight salty taste in 1970. Ground water in aquifers disturbed by strip mining frequently has been degraded by the addition of products produced by the oxidation and leaching of some of the iron minerals associated with the coal. Ahmad (1971) suggests that, even after reclamation of stripped land in southern Ohio, ground-water quality is seriously impaired for many years.

The solution to the problem of non-functioning septic systems and poor water quality in wells can only be the installation of sewers and a sewage-treatment plant, and a water-treatment and water-distribution system. As good-quality ground water is not available in the area, water would have to be piped in from the Illinois River and treated. With the added expense of these installations, the area would no longer be economically possible as a site for the summer homes of middle-income people.

The problem of stability of waste piles is illustrated in Figure 2, which shows a small land slip. Slides of this sort are common in steep man-made piles of debris whose slopes exceed the normal angle of repose of such materials, particularly in sites where the weight of a house increases the tendency for slippage to occur. Careful research into the stability of slopes on waste piles is necessary prior to development of home sites on reclaimed waste piles.

Environmental problems are compounded by poorly planned reclamation at two northeastern Ohio strip-mined sites, where refuse has been used to fill the

excavations. One site had an existing problem of large discharges of acid drainage. Solid wastes, improperly emplaced, yielded a polluted seepage, or leachate, which, added to the acid drainage, increased the pollution of the flow from the site. Hydrogeologic study of the site would have warned of the inevitability of this problem.

The other site is situated on an exposure of a sandstone aquifer created by stripping activities. The operator, without knowledge of the proximity of the



FIGURE 2. Rock slip and rock fall in highwall of abandoned strip mine, illustrating potential hazard to developers of old strip mines.

aquifer, was dumping liquid and solid wastes into the pit. In addition to the capability of the liquid to enter the aquifer through the pores in the material, liquids had also traveled some distance from the site through an old mine-tunnel system adjacent to the strip mine. Wells polluted by this material occur at distances of as much as one-half mile from the fill. After several months of complaints and a court injunction, the operator ceased disposal of liquid wastes,

but not of solid wastes. Even though no new liquid wastes are being dumped here, though, considerable amounts of contaminants from the earlier disposal will continue to move through the aquifer, increasing the contamination in the water in these nearby wells for some time to come.

If a strip mine is to be used for refuse disposal, the geologic and hydrogeological conditions of the site must first be investigated. The depths to potential aquifers, the nature and arrangement of the permeable and impermeable materials present in the ground, the direction of ground-water flow, and the direction of surface-water drainage must all be determined prior to the consideration of the use of a strip pit for a sanitary landfill or liquid-waste disposal-site. With this knowledge, the idea of these sites for such refuse can either be abandoned or implemented, and if necessary, adequate site engineering, such as the construction of impermeable liners or artificial leachate drainage systems (Hughes, Landon, and Farvolden, 1971), can be instigated. A refuse-filled strip mine can eventually become land suitable for agriculture or recreation.

Sand and Gravel Pits

Many abandoned sand and gravel pits offer unique opportunities for land development. Many large abandoned sand and gravel pits are located very near large urban centers because they contain a commodity that requires close



FIGURE 3. Corn growing in mined-out sand and gravel pit, representing a good interim land-use of derelict land.

markets to be economic. Land values in such areas near the cities are high, with numerous uses vying for the land, but the gravel-excitation process creates features attractive to residential development, such as steep slopes and large bodies of clear, deep water in areas that might otherwise be lacking in these features (Bauer, 1965).

Research by the Sand and Gravel Association and the University of Illinois (Bauer, 1965; Johnson, 1966; Jensen, 1967) has shown the value of simultaneous excavation and reclamation of sand and gravel excavation areas. This concept is one of levelling and filling, where necessary, mined-out sections of the excavation prior to or contemporaneous with initiating gravel extraction in new parts of the pit. Advantages of such immediate reclamation are: the equipment is in the area and need not be moved back to the site for reclamation; slopes can be planted and will have time to stabilize; and the general appearance of the site is improved.

In McHenry County, Illinois, a sand and gravel operator removed material to a depth of 80 feet over a 70-acre site. Upon completion of extraction, top soil stockpiled nearby was returned to the area and corn planted (fig. 3). The operator does not plan on agriculture as a final land use, but the land is no longer derelict, and it may well lead to higher value residential development.

The principal problems associated with development in abandoned sand and gravel areas are essentially the opposite of those in the strip-mine areas. In sand and gravel pits, the surficial materials have high infiltration capacities and high percolation rates. The ground may accept septic effluent too rapidly to provide sufficient filtration, which may result not only in contamination of the ground water, but also of any water body in the pit fed by ground water. Geological evaluations of the materials and of the flow direction of the ground water should be made prior to the development of any subdivision plan that might call for wells and septic tanks.

Slopes in sand and gravel pits will eventually collapse to the normal angle of repose of the material (less than 20°—Lambe and Whitman, 1969). Exposed sheer walls in active sand and gravel pits are especially impermanent, so initial geologic recommendations should include slope stabilization. Should structures such as houses be added at the tops of such unstable slopes, early failure of the slope (and of the structure on top of it) is even more likely.

Geologic-Hazard Regions

In north-central United States, the principal geologic hazards are landslides and related earth movements. Landslides in this region occur in bedded lake silts (Rau, 1968; Lounsbury, and Melhorn, 1971), in clay-rich shale (Fisher, 1968; Du Montelle, *et al.*, 1971) and in slopes oversteepened by highway construction. Areas with high landslide potential are subject to reclamation for three reasons: frequently the land is cheap; the steep slopes which are usually the most active give the best vistas; and engineers and geologists have developed stabilization techniques which give a fair degree of safety.

Although most landslides cause only economic problems (associated with loss of property, highway destruction, and house foundation failure), loss of life can be associated with major landslides. A large residential development in the town of Saint-Jean-Vianney near Quebec, Canada, was subjected to a major slide on May 4th, 1971, which caused the loss of 31 lives and the complete destruction of 40 single family houses (Tavenas, Chagnon, and LaRochelle, 1971).

Geological mapping of slope areas can indicate the potential for sliding. To date, most mapping of landslides and landslide-active areas has been accomplished after the slides have occurred. However, the United States Geological Survey is presently undertaking a project of mapping landslide-active regions in Pennsylvania and in California, and to define risks in these areas.

Water is usually the triggering agency for a landslide. Water increases the weight of the material in the slope until the downward force is greater than the resisting force, and failure occurs. Water acts as a lubricant, reducing frictional resistance to sliding. Many clay minerals expand when exposed to water, and certain saturated clays flow, as in the case of the Saint-Jean-Vianney slide near Quebec (Tavenas, Chagnon, and La Rochelle, 1971). Reclamation techniques

for landslide-prone slopes usually involve reduction of water infiltration by drains at the head of the slope, drainage of water from the toe of the slope, and addition of chemical additives to stabilize clays. Constructing retaining walls, terracing the slope, and removing material at the head of the slope to reduce the weight are also techniques used to control slides. All of these engineering works are similar to those associated with floodplain protection in that they do not make the slope completely safe for all uses, but can at least lower the frequency of sliding and make land suitable for low-intensity use.

A good example of low-risk land-use on an active slope is a ski run near Peninsula, Ohio. The operator has not stabilized the slope in any way, but has merely smoothed the slope to eliminate steep drops created by gullies. Slides occur yearly, but only in the spring, and so do not destroy the operation, which is in intensive use only in the winter. The operator does have a considerable maintenance problem with the ski lifts, due to land movements and to erosion, but these problems are easily taken care of during the summer months and hummocks left by slumping actually add to the skiing enjoyment. Diversion ditches at the head of the slope, and gravel-filled drainage ditches on the slope would help control both the sliding and the erosion of the hill surface.

CONCLUSIONS

Future reclamation of much land may be necessary to satisfy adequately the food and space needs of an expanding population. Properly reclaimed land can be made available for agriculture, recreation, forests, and housing developments.

Land reclamation of perennially wet areas for agriculture has been accomplished by drainage, engineering work that required a minimum of geologic input. Reclamation of land for housing, industry, or recreation requires ecologic, hydrologic, and geologic data in addition to the engineering analysis. The geologist can contribute in the planning for reclamation of floodplains, wetlands, strip-mined land, and geologic-hazard regions. Geologic data can be used to predict an environmental impact precipitated by a reclamation project.

In Illinois and Ohio, intensive use of some seemingly waste land or of reclaimed land has intensified problems of flooding, surface-water pollution, ground-water pollution, and landslides. Floodplains and landslide-prone slopes can be reclaimed only to the point where flood or landslide frequency and magnitude may be reduced, but not eliminated. Low-intensity uses of flood-plains such as forest preserves, farming, or parks (green belts) are frequently the best land utilizations. Landslide-active slopes may be best used as open space or recreation areas.

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